Application of Shear Force Spectral Analysis in STI CMP

Y. Sampurno [1], F. Sudargho [1,2] , Y. Zhuang [1,2], T. Ashizawa [3], H. Morishima [3] and A. Philipossian [1,2]

[1] Department of Chemical Engineering, University of Arizona, Tucson, AZ, USA
[2] Araca, Inc., Tucson, AZ, USA
[3] Hitachi Chemical Co. Ltd., Tokyo, Japan

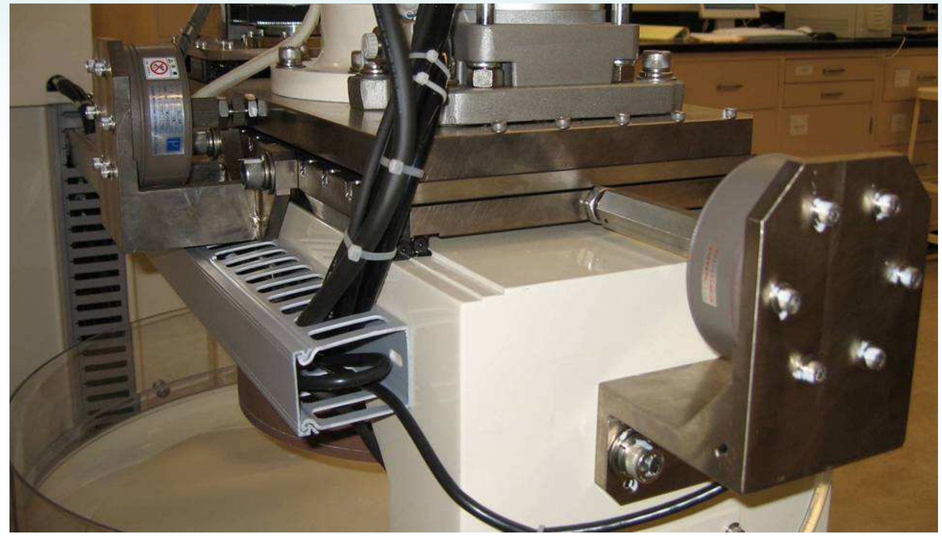
Outline

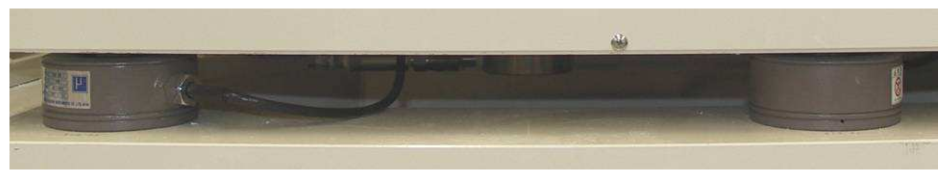
1. Objectives
2. Polishing Apparatus
3. Abrasive Particle Size Studies
4. STI Patterned Wafers Studies
5. Summary

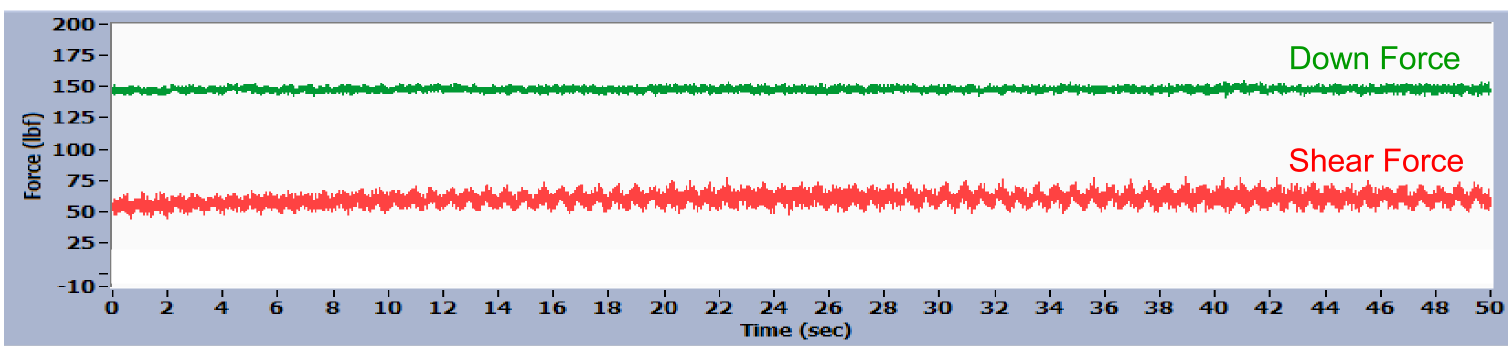
Objectives

- **Investigate the effect of abrasive particle size (in ceria-based slurries) on:**
  - **Shear force (F_y)**
  - **Coefficient of friction (COF)**
  - **Removal rate (RR)**
- **Determine whether spectral analysis (based on raw force data) can generate unique spectral fingerprints before, during and after transition to Si_3N_4 during polishing of STI patterned wafers**

The Araca APD – 500 Polisher & Tribometer







F_z

F_y

Abrasive Particle Size Studies

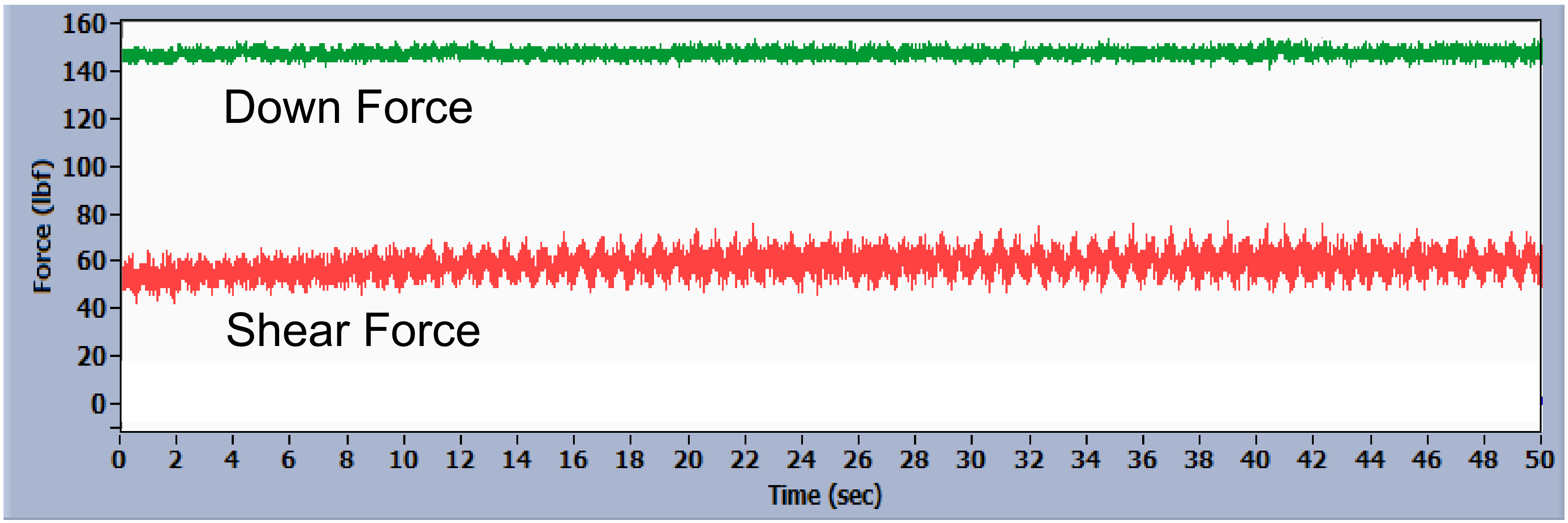
Experimental Conditions

- **Diamond disc conditioner: 107 mm MMC TRD 100 grit**
- **Conditioning force: 5.8 lb_f (25.8 N)**
- **Conditioning : *In-situ* at 30 RPM disc speed & 10 per minute sweep frequency**
- **Wafers: 200 mm blanket PETEOS**
- **Wafer pressure : 3 PSI (20.7 KPa)**
- **Sliding velocity : 93 RPM for platen and 87 RPM for wafer carrier**
- **Slurry flow rate : 200 cc/min**
- **Slurry: Four different ceria-based slurries**

	I	II	III	IV
D_{50} (nm)	160	180	190	200
D_{99} (nm)	400	500	700	1000

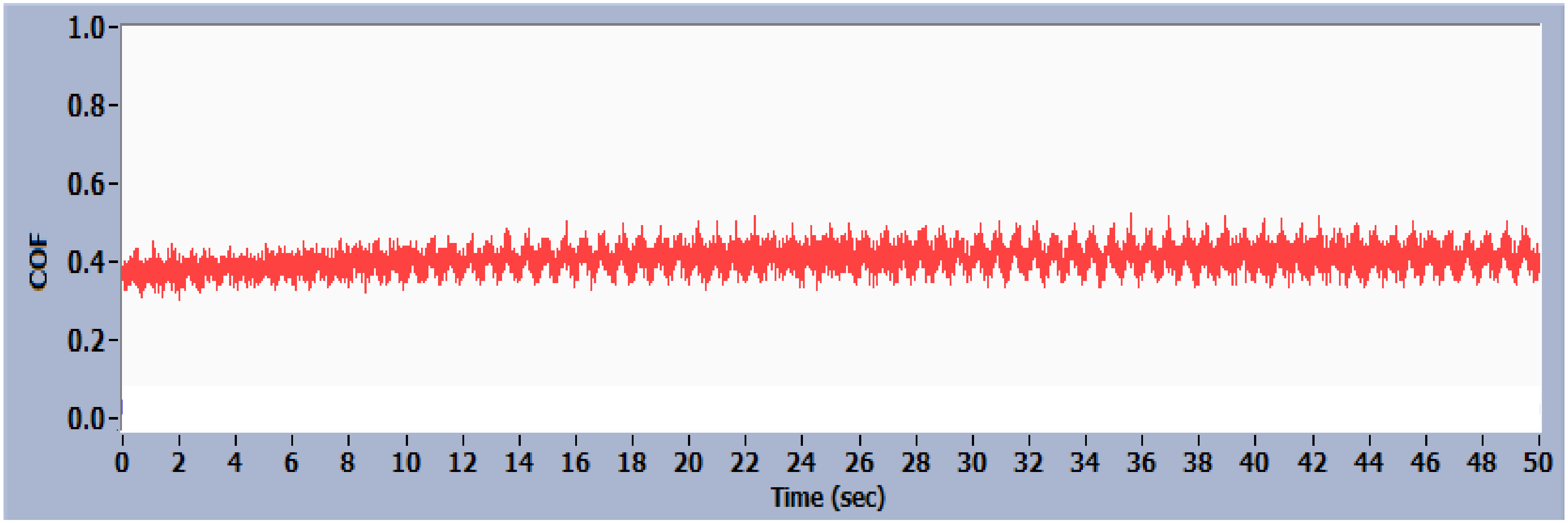
- **Pad : 500 mm RHEM IC1000 A2 K groove**
- **Polishing time: 60 seconds**

Raw Force Measurement



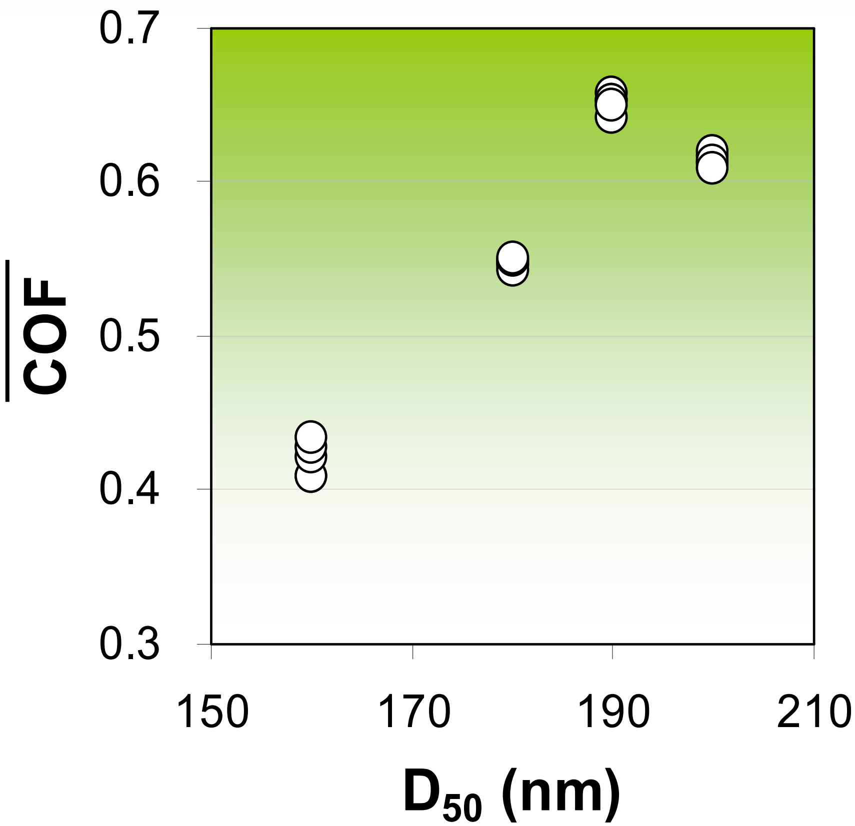
$$COF_i = \frac{\text{Shear Force}_i}{\text{Down Force}_i}$$

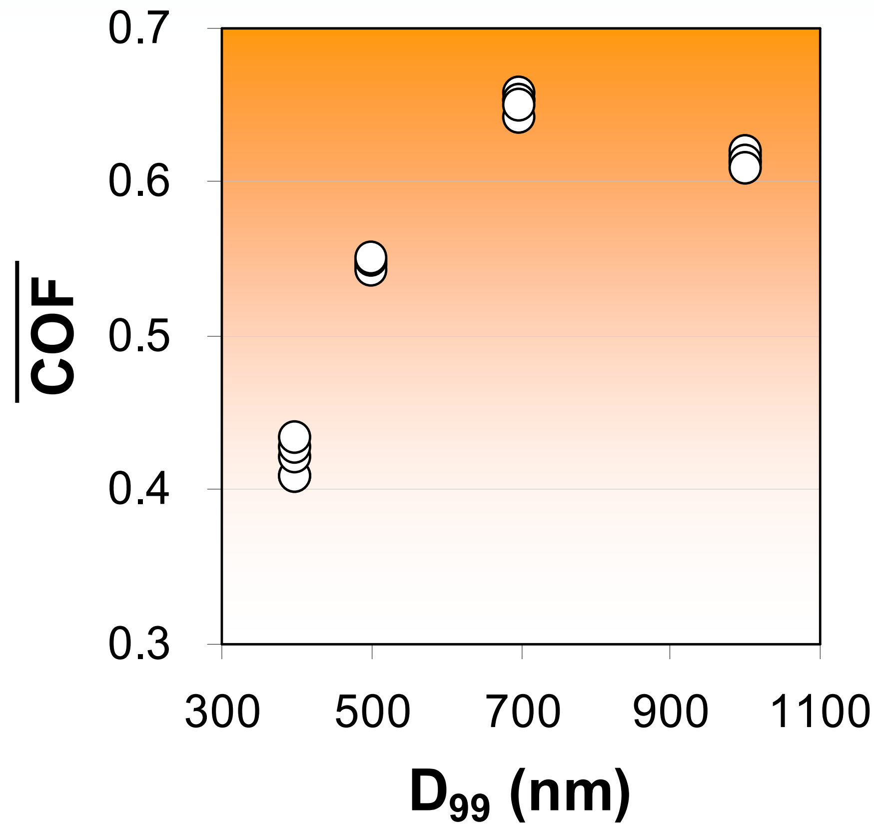
Coefficient of Friction (COF)



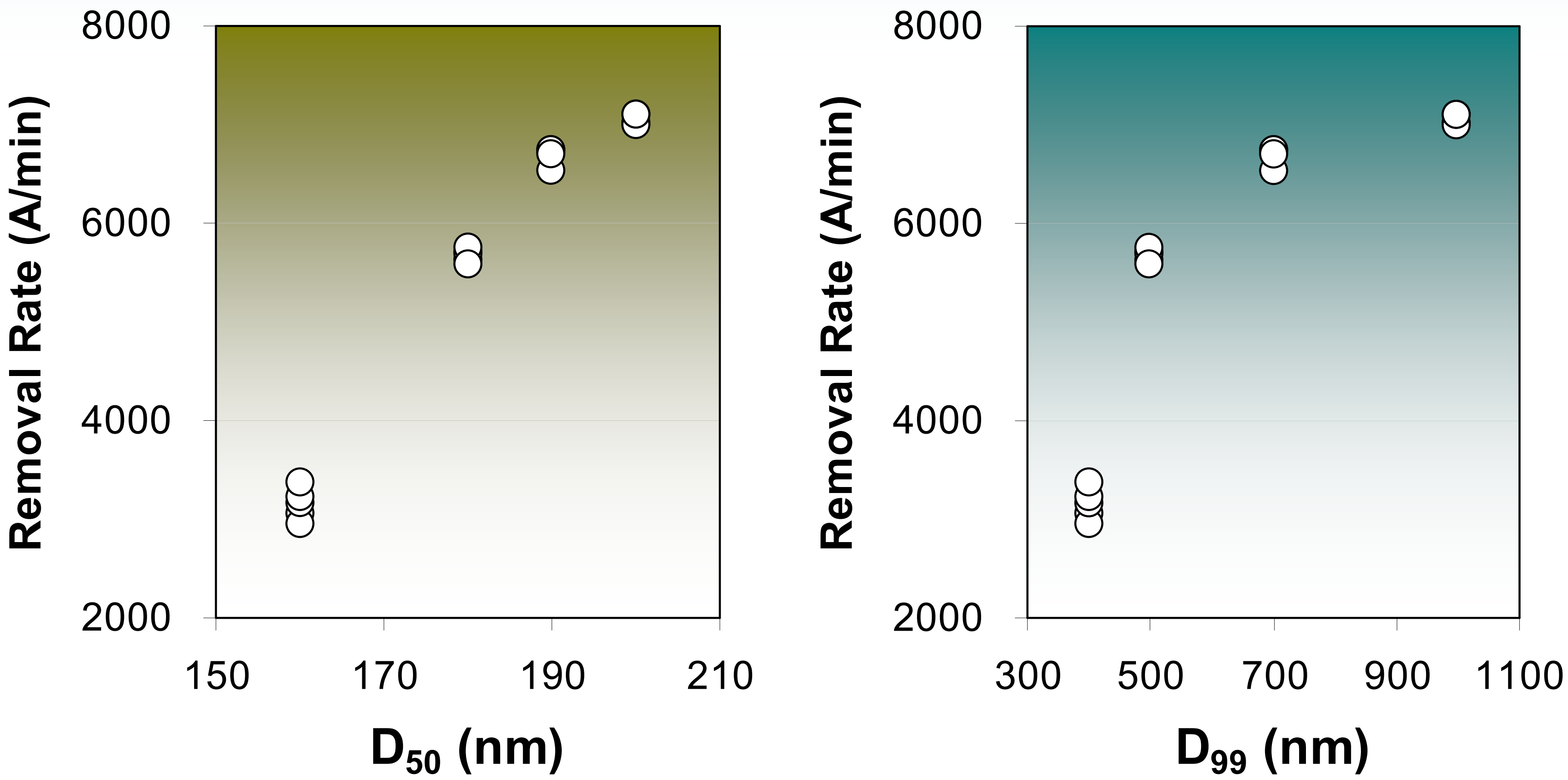
$$\overline{COF} = \frac{\sum_i COF_i}{i}$$

COF Results (n = 5)

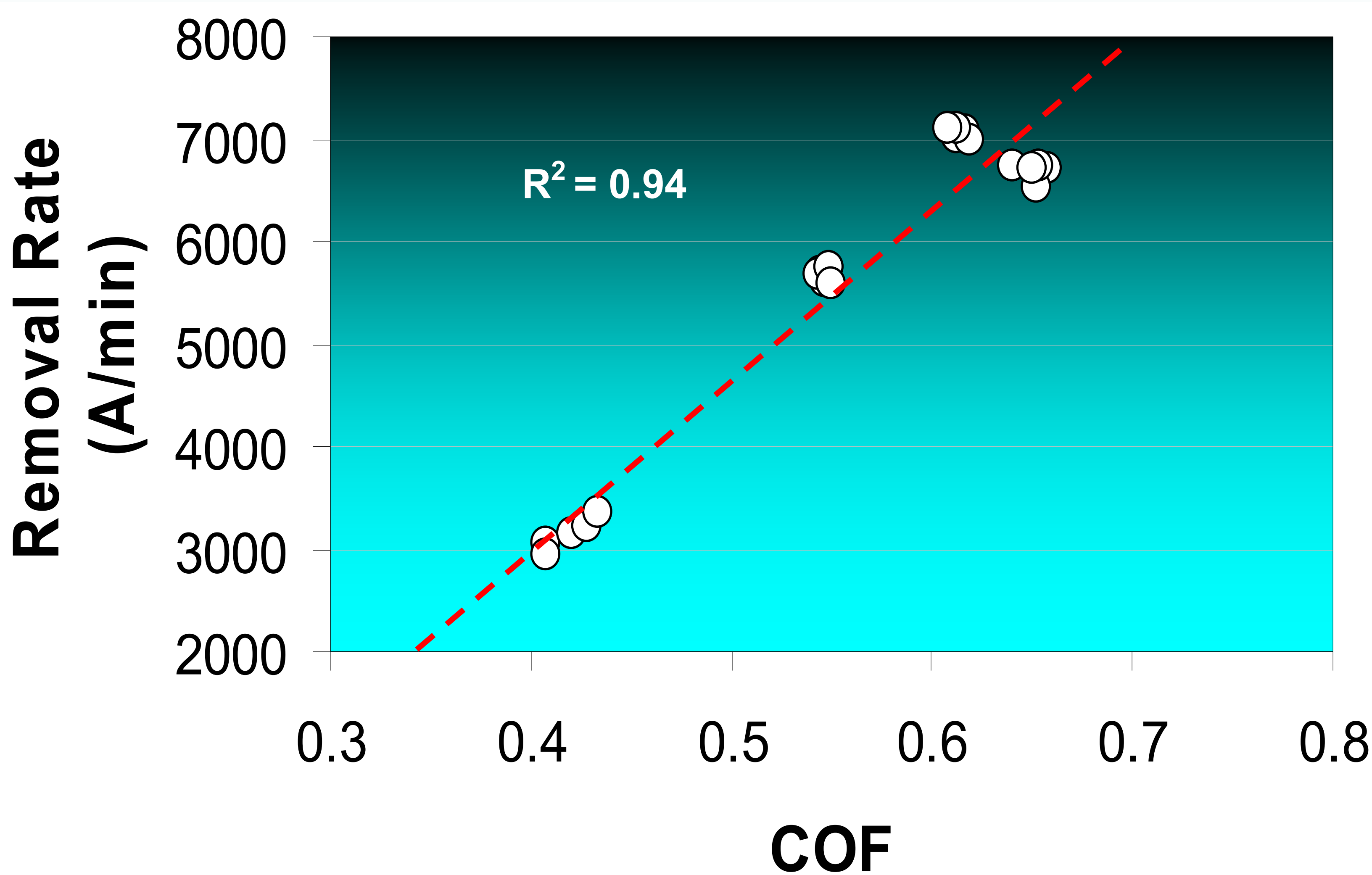




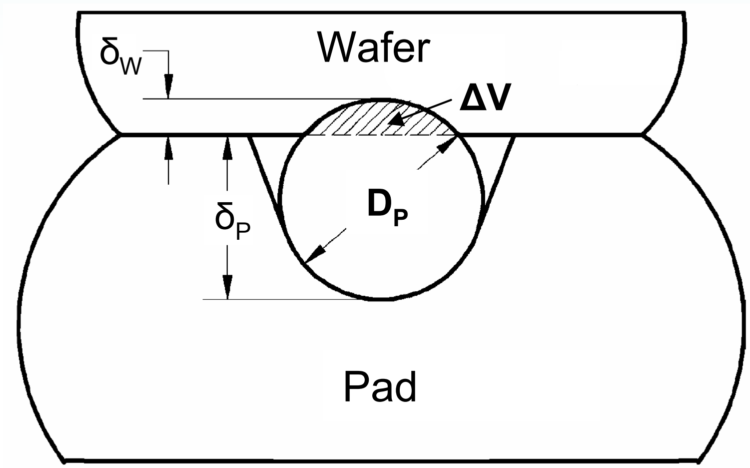
Removal Rate Results (n = 5)



Correlating RR to COF for all 4 Slurries



Modeling the Effect of Abrasive Particle Size



$$F_{cp} = F_{cw}$$

$$\frac{4}{3} E_{cp} \left(\frac{D_p}{2} \right)^{1/2} \delta_p^{3/2} = H_w \pi D_p \delta_w$$

$$\delta_w + \delta_p = D_p$$

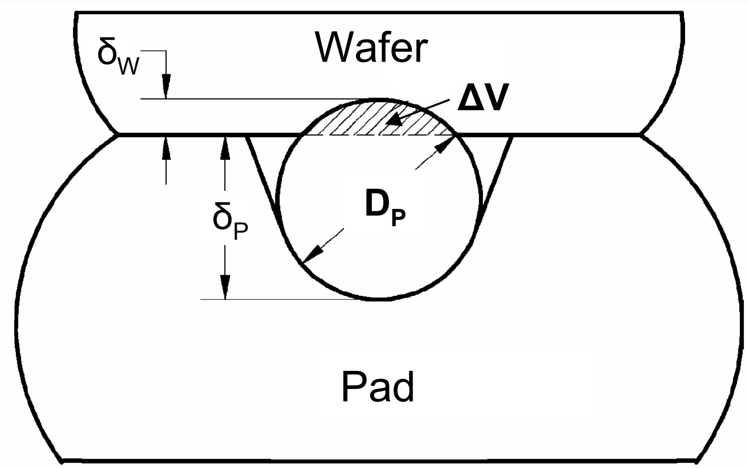
$$\delta_w^3 + \left(\frac{9\pi^2}{8} \frac{H_w^2}{E_{cp}^2} - 3 \right) D_p \delta_w^2 + 3 D_p^2 \delta_w - D_p^3 = 0$$

$$H_w = 8.3 \times 10^9 \mathrm{Pa}$$

$$E_{cp} \approx E_{sp} = 3.33 \times 10^7 \mathrm{Pa}$$

K. Johnson, Contact Mechanics (1985)
Y. Zhao and L. Chang, Wear ***252:*** *220-226 (2002)*

Modeling the Effect of Abrasive Particle Size



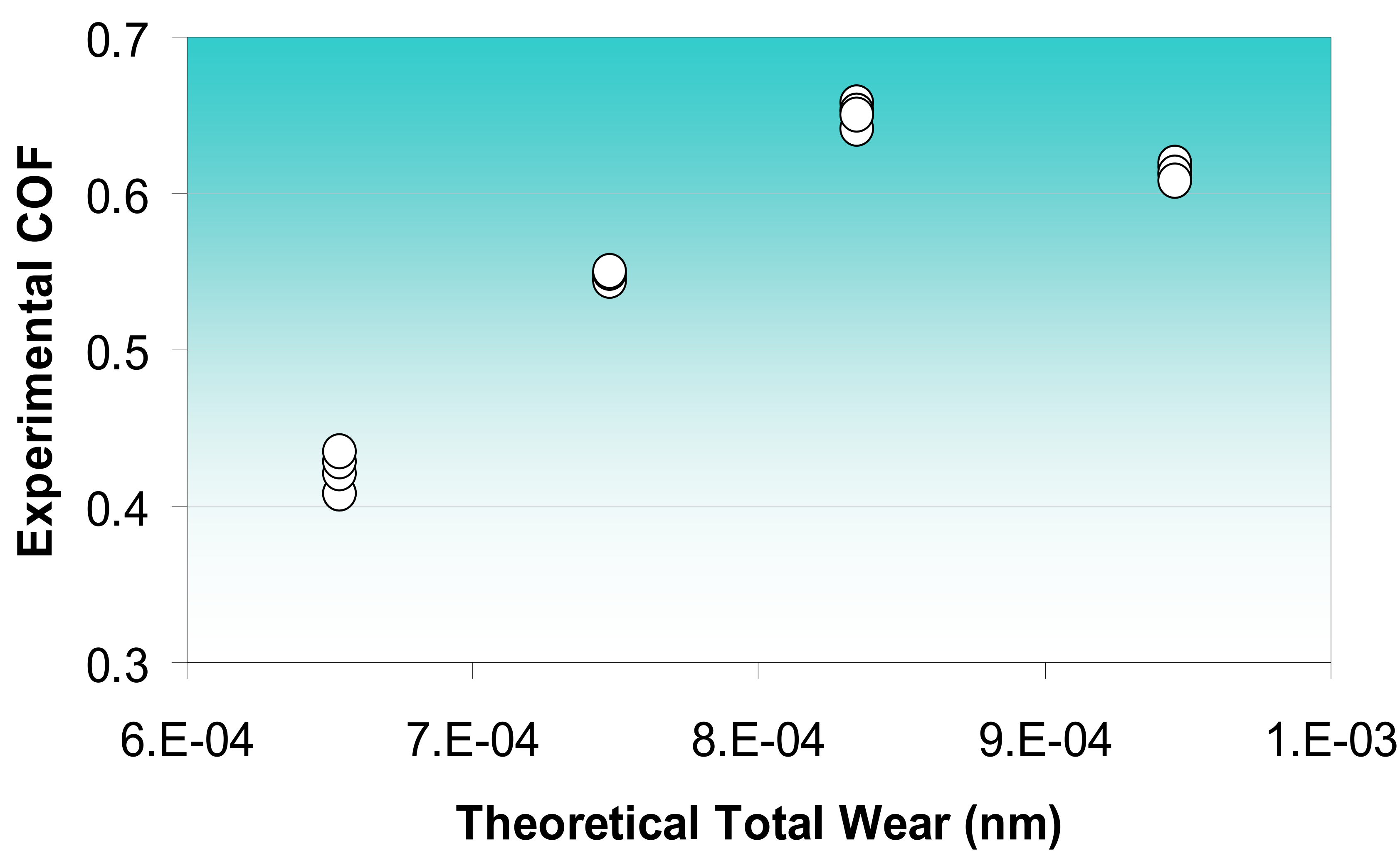
$$\Delta V = \pi \left(\frac{D_p^2 \, \delta_w}{4} + \frac{\left(D_p - \delta_w\right)^3}{3} - \frac{D_p^3}{6} \right)$$

$$N_a = A_t \left(\frac{6 \, X_v}{\pi \, D_p^3} \right)^{2/3} \qquad N_{ao} \approx \left(\frac{6 \, X_v}{\pi \, D_p^3} \right)^{2/3}$$

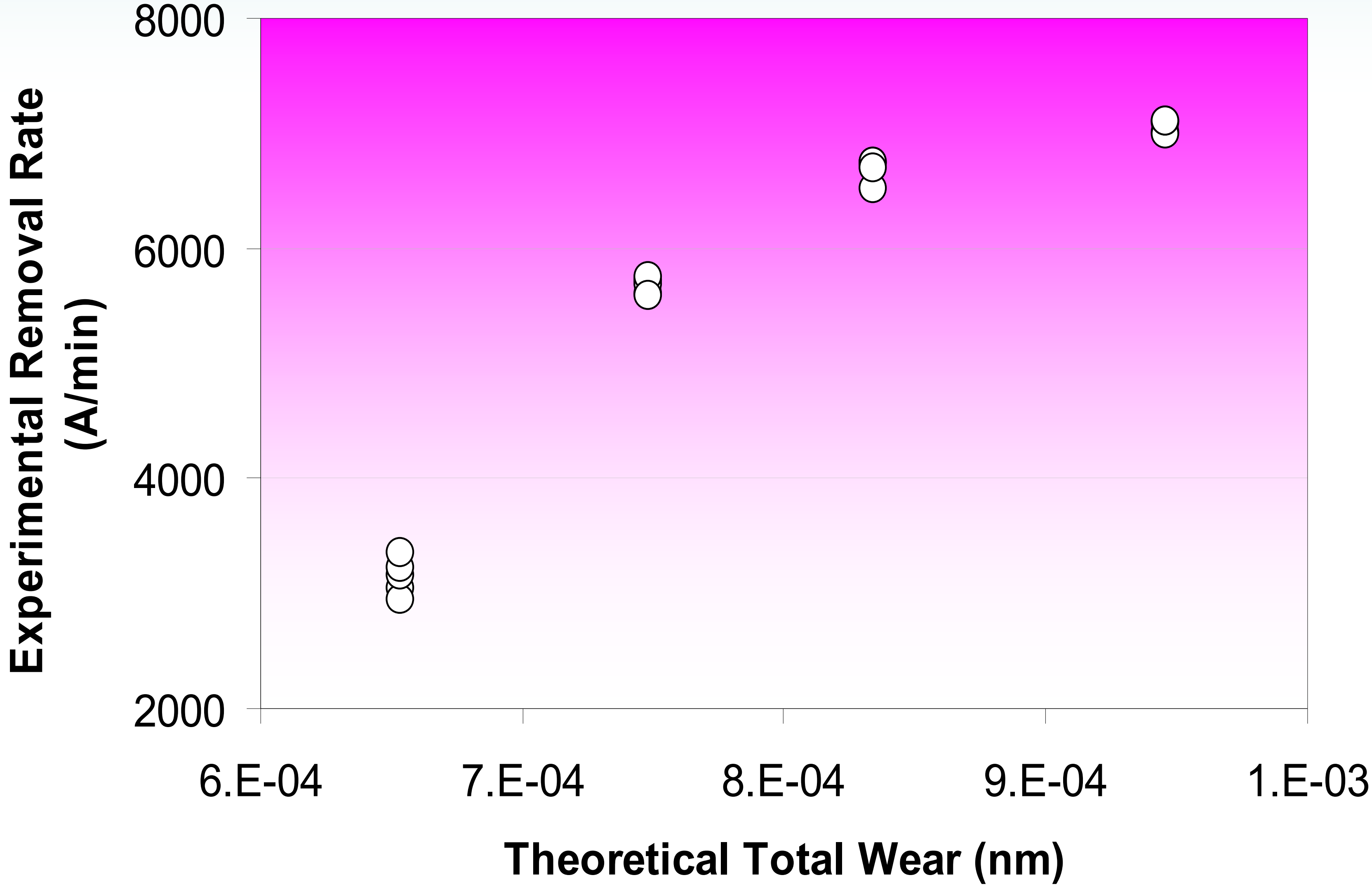
$$\text{Wear} \approx \Delta V . N_{ao}$$

	D_{50}					D_{99}					Total Wear (nm)
	D_P (nm)	δ_w (nm)	ΔV (nm^3)	N_{ao} (nm^{-2})	Wear (nm)	D_P (nm)	δ_w (nm)	ΔV (nm^3)	N_{ao} (nm^{-2})	Wear (nm)	
Slurry 1	160	0.19	9.3	5.97E-5	5.51E-4	400	0.48	145.1	4.47E-7	1.03E-4	6.19E-4
Slurry 2	180	0.22	13.2	4.72E-5	6.20E-4	500	0.60	283.4	2.86E-7	1.29E-4	7.05E-4
Slurry 3	190	0.23	15.6	4.24E-5	6.54E-4	700	0.84	777.6	1.46E-7	1.80E-4	7.72E-4
Slurry 4	200	0.24	18.1	3.82E-5	6.89E-4	1000	1.20	2267.2	7.14E-8	2.57E-4	8.55E-4

Correlating COF to Theoretical Extent of Wear



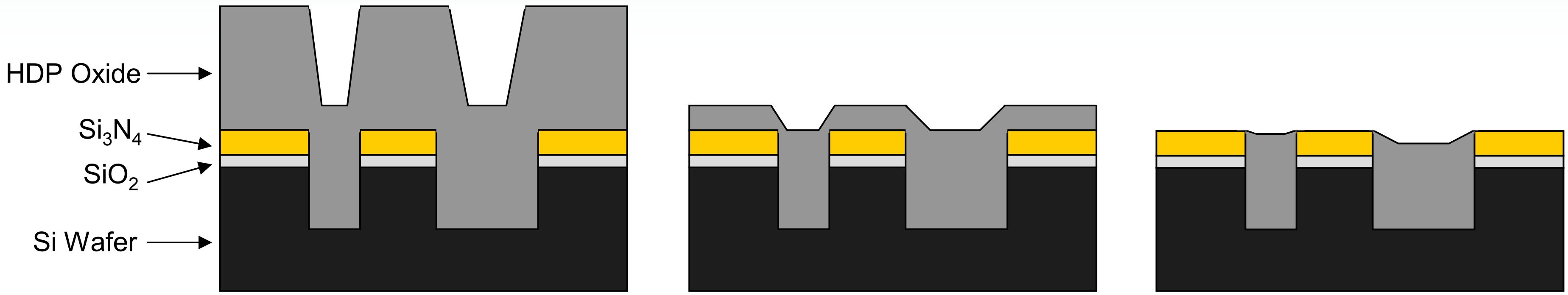
Correlating Experimental RR to Theoretical Extent of Wear

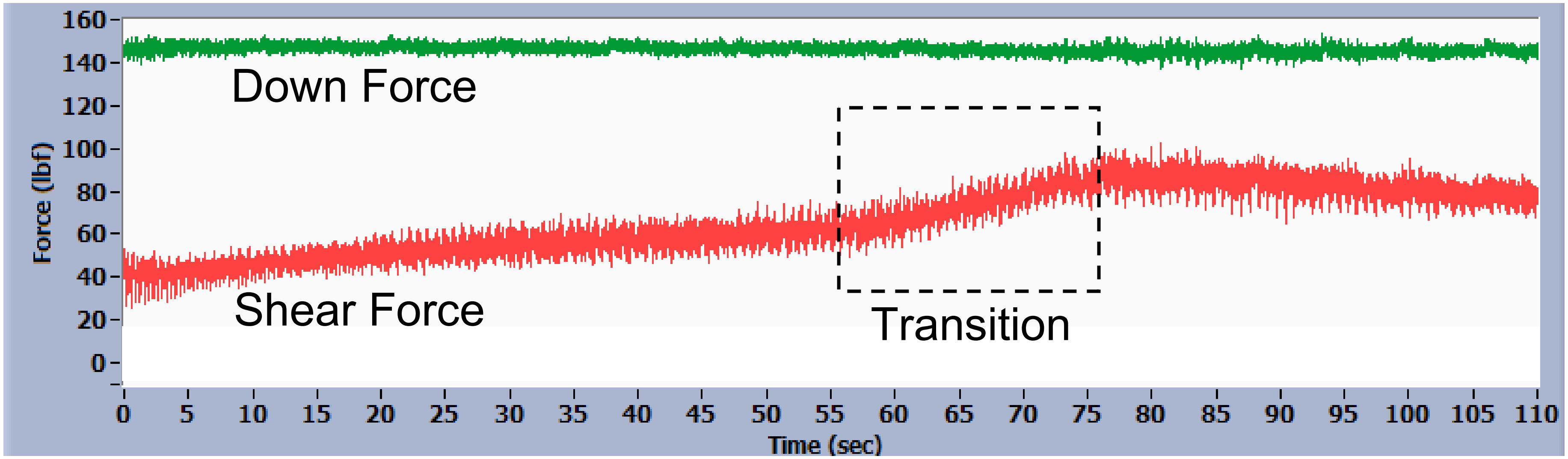


STI Patterned Wafer Studies
Experimental Conditions

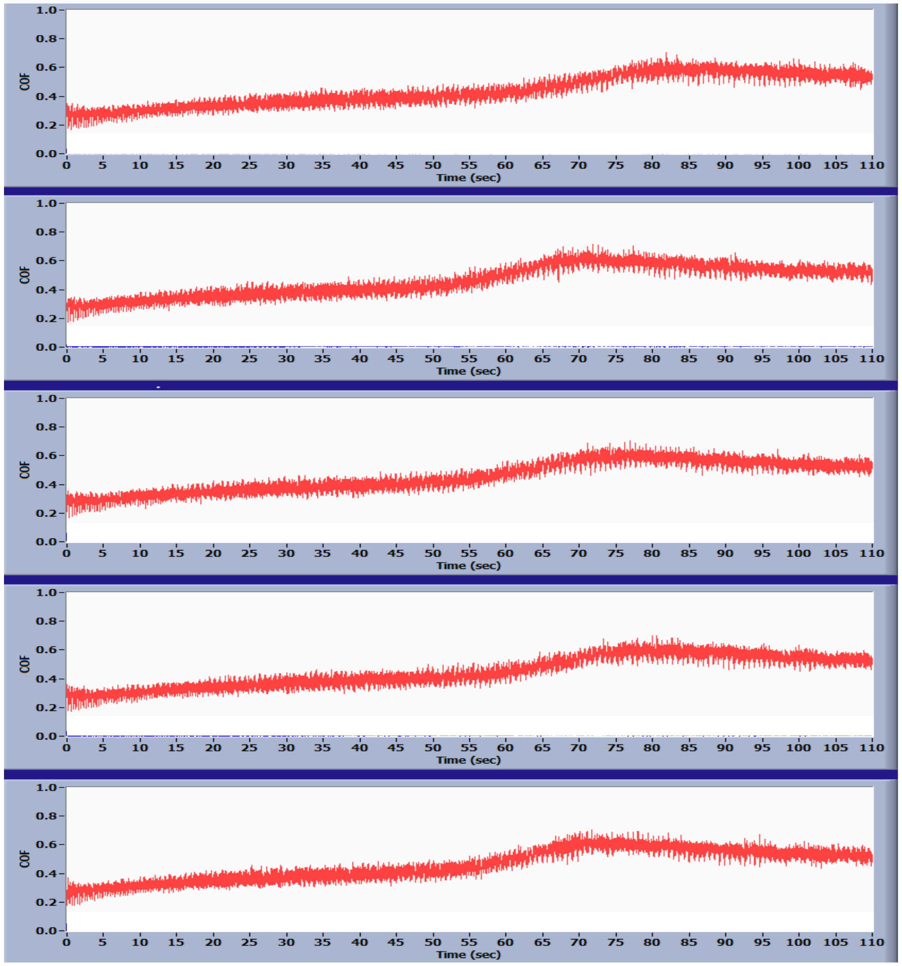
- Diamond disc conditioner: 107 mm MMC TRD 100 grit
- Conditioning force: 5.8 lb_f (25.8 N)
- Conditioning : *In-situ* at 30 RPM disc speed & 10 per minute sweep frequency
- Wafers: 200 mm SKW STI patterned wafers
- Wafer pressure : 3 PSI (20.7 KPa)
- Sliding velocity : 93 RPM for platen and 87 RPM for wafer carrier
- Slurry flow rate : 200 cc/min
- Slurry: Ceria-based slurry with D_{50} of 190 nm (D_{99} of 700 nm)
- Pad : 500 RHEM IC1000 A2 K groove
- Polishing time: 110 seconds

Shear Force Measured on STI Patterned Wafers





COF Transients for 5 Wafers



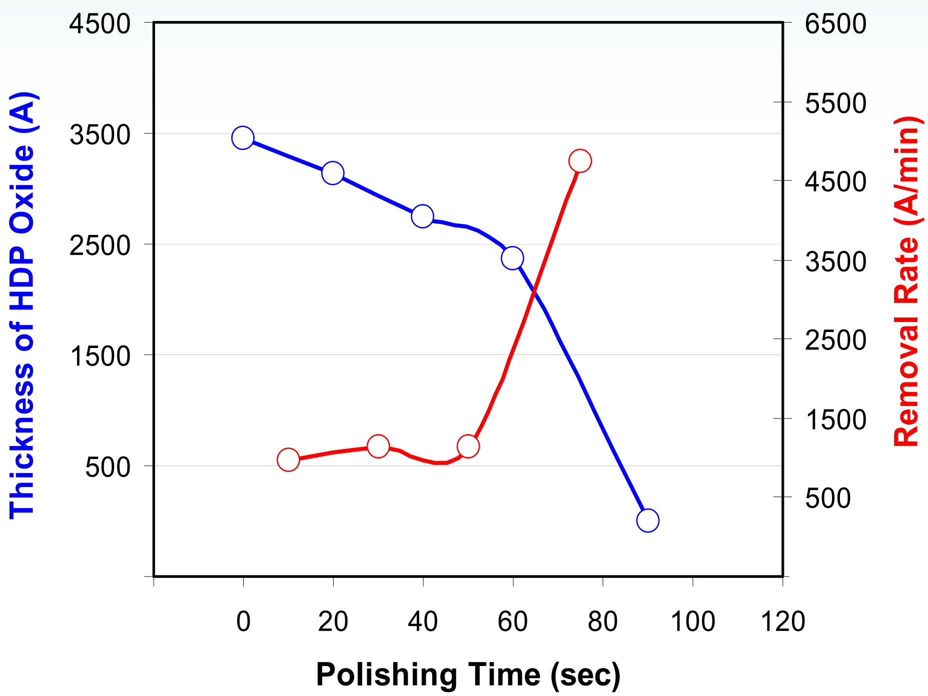
Polish Time

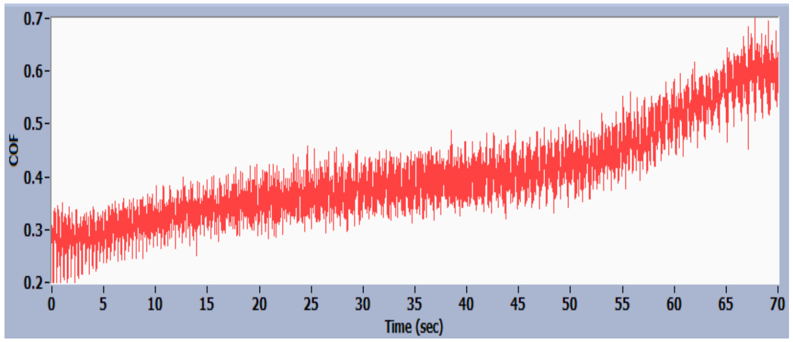
	Transition Start (s)	Transition End (s)
Average	56.4	71.4
SD	3.4	4.5
RSD	6.1%	6.3%

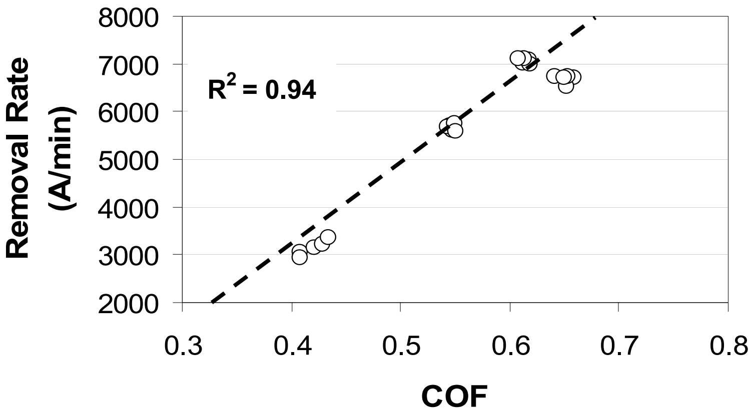
Coefficient of Friction

	Before Transition	During Transition	After Transition
Average	0.361	0.510	0.566
SD	0.004	0.006	0.008
RSD	0.1%	0.3%	0.5%

Comparing to Data in the Literature



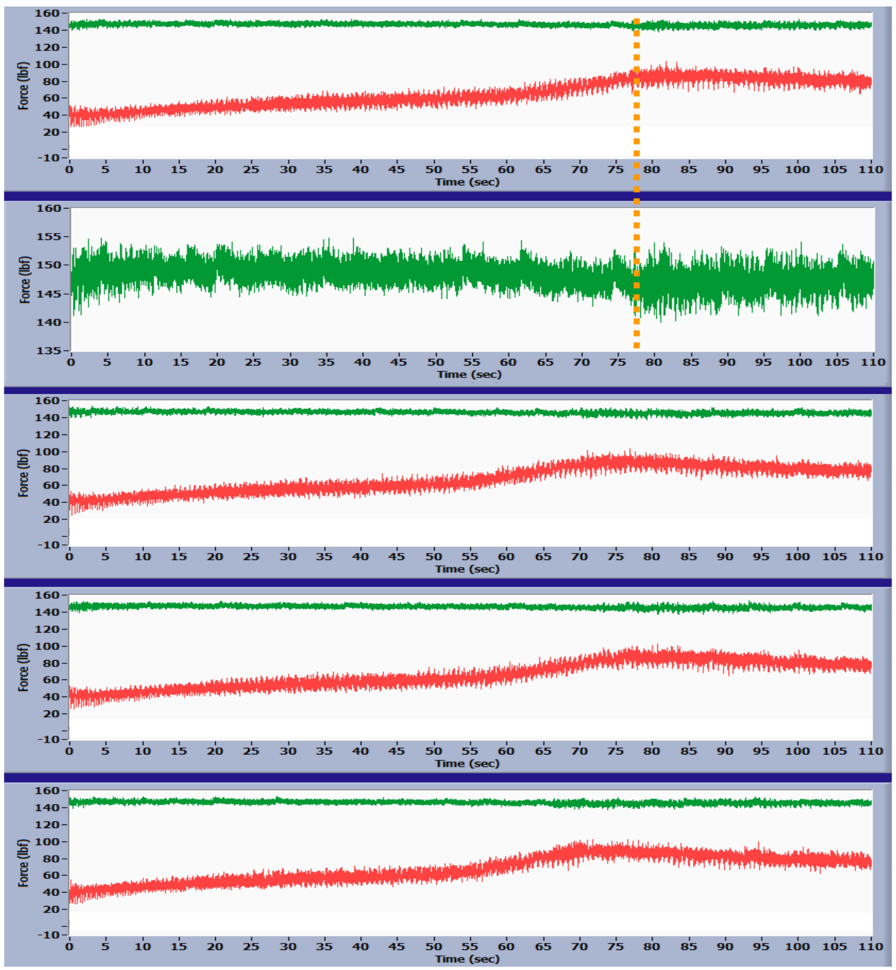




- STI patterned wafer
- Ceria slurry
- Mean particle size = 312 nm
- IC1000 pad

*D. Lim et al., Surface & Coatings Technology **200**:1751-1754 (2005)*

Force Transients for 5 Wafers



Polish Time

	Transition Start (s)	Transition End (s)
Average	56.4	71.4
SD	3.4	4.5
RSD	6.1%	6.3%

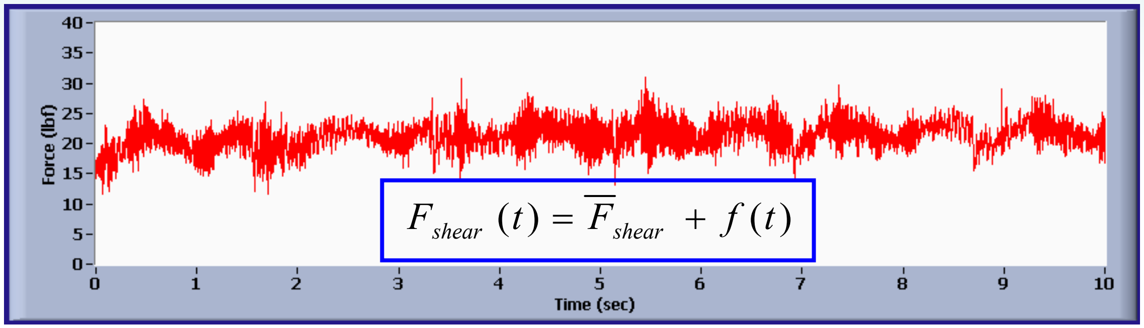
Variance of Shear Force (σ^2)

	Before Transition (lb_f^2)	During Transition (lb_f^2)	After Transition (lb_f^2)
Average	58.7	57.8	33.6
SD	2.8	7.7	9.2
RSD	4.7%	13.3%	27.4%

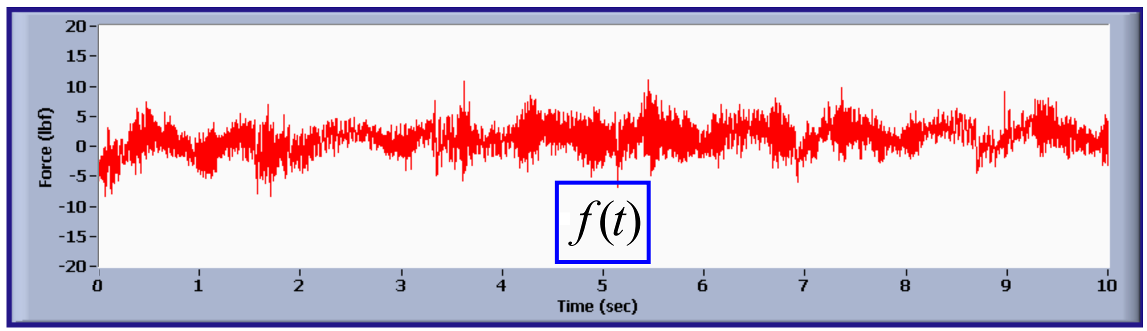
Variance of Down Force (σ^2)

	Before Transition (lb_f^2)	During Transition (lb_f^2)	After Transition (lb_f^2)
Average	2.3	2.2	3.4
SD	0.03	0.22	0.19
RSD	1.3%	10%	5.5%

Spectral Analysis of Raw Force Data

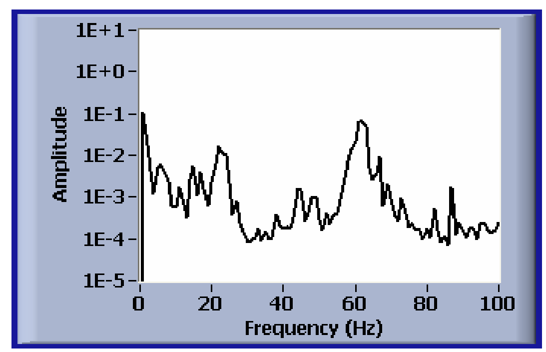


Subtracted by $\overline{F}_{shear}$



Time domain → Frequency domain

Fast Fourier Transform

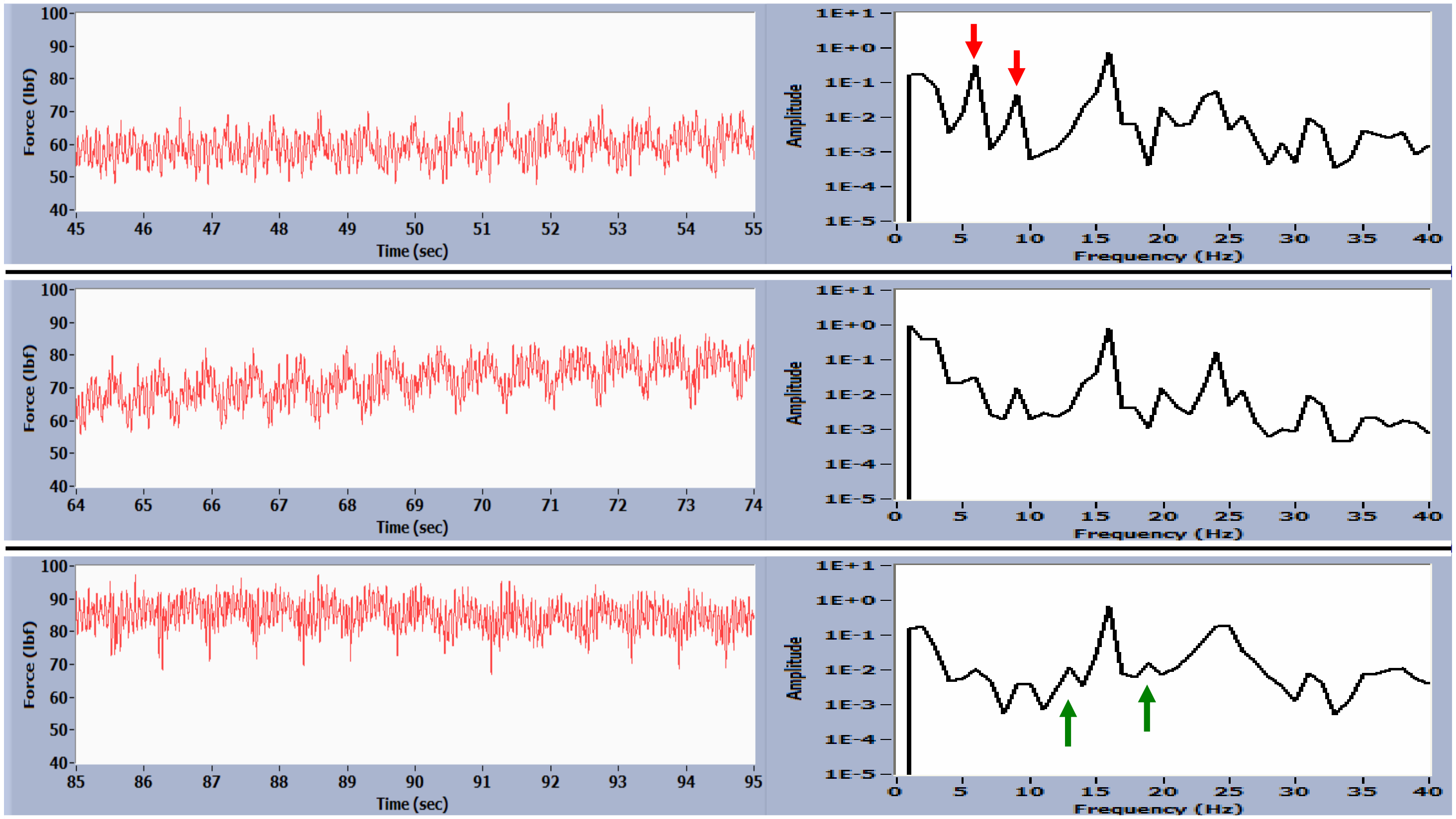


Spectral Analysis of Shear Force for STI Patterned Wafer No. 1

Before Transition

During Transition

After Transition

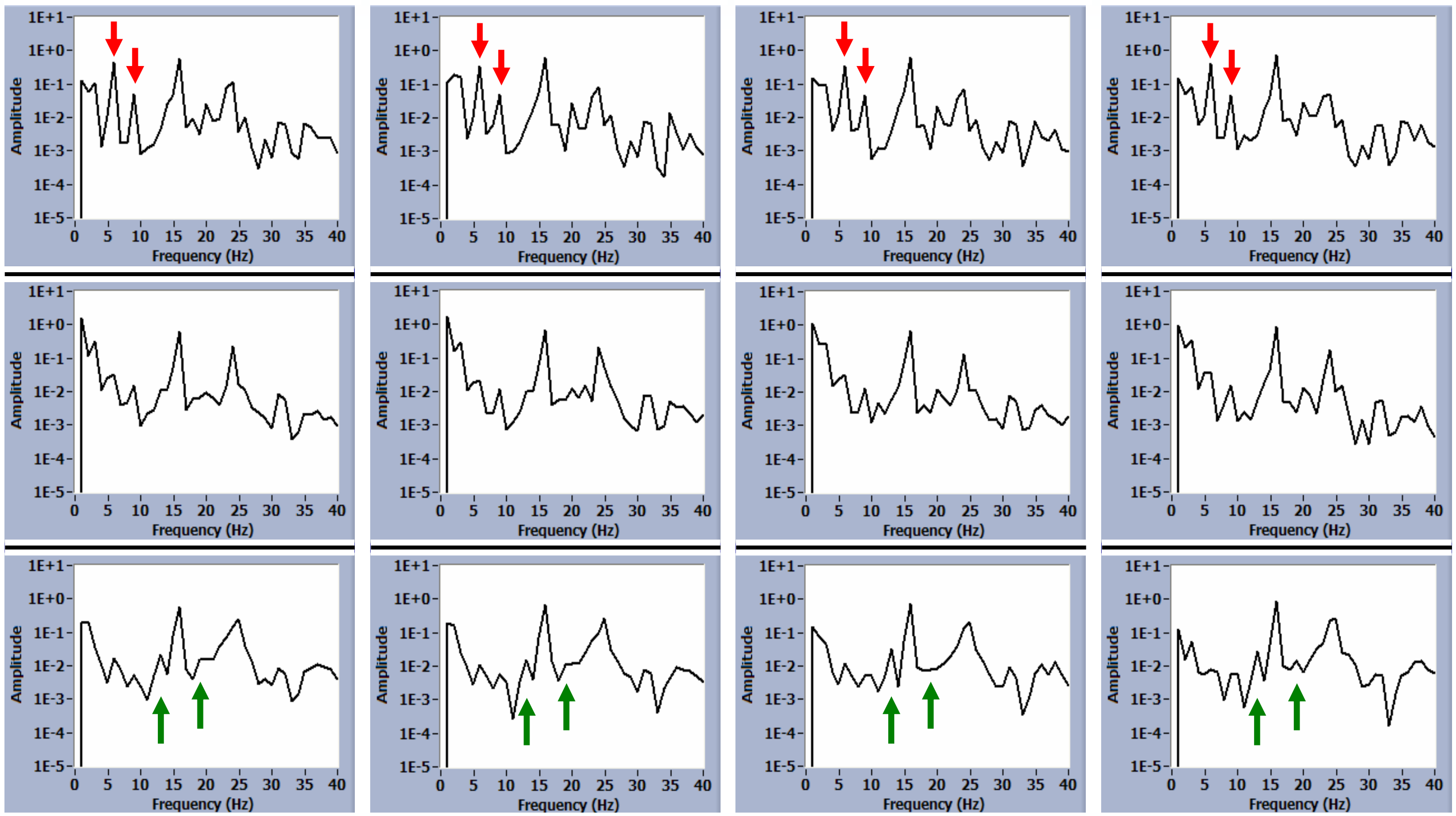


Spectral Analysis of Shear Force for Wafer Nos. 2 – 5

Before Transition

During Transition

After Transition

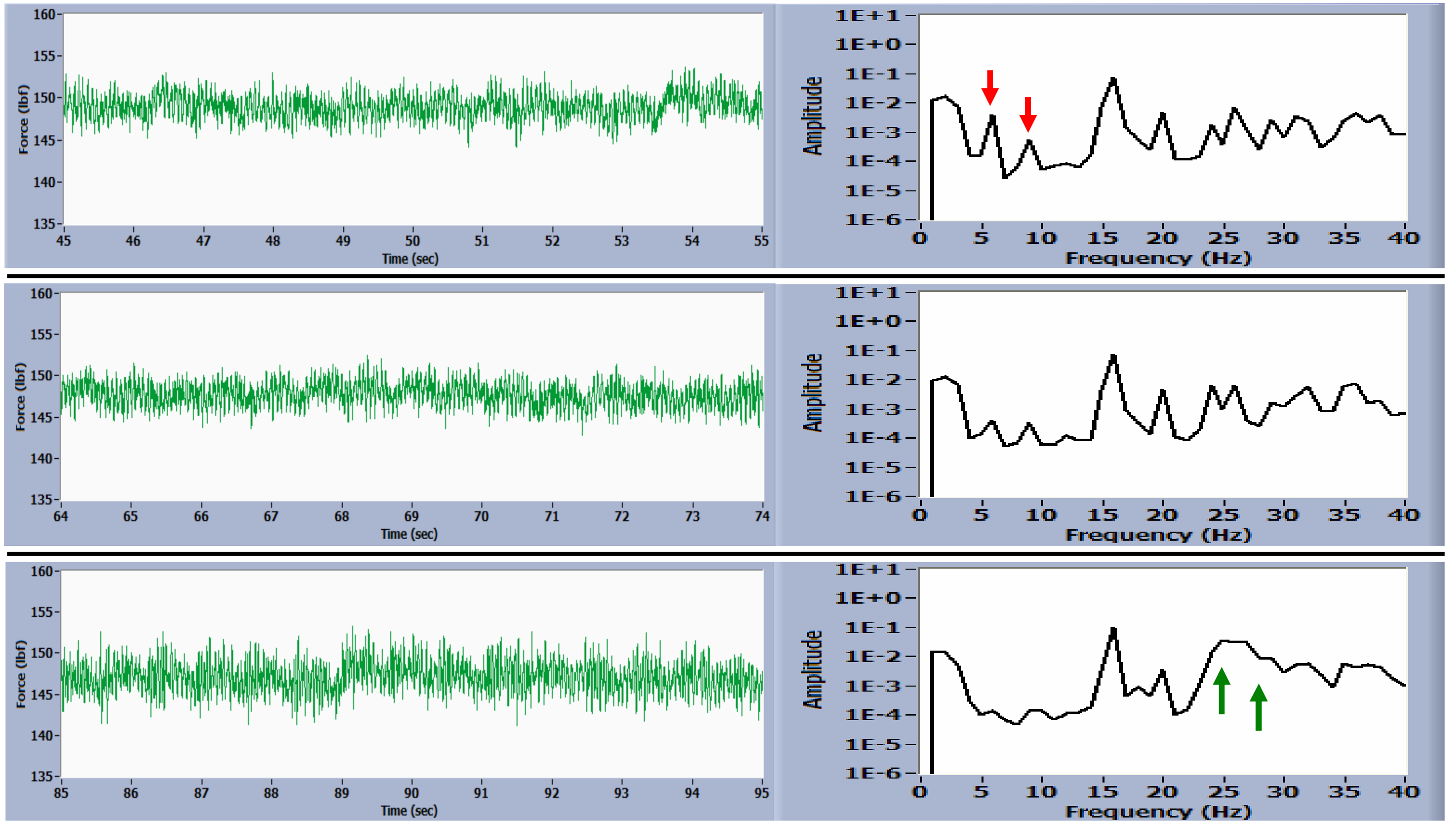


Spectral Analysis of Down Force for STI Patterned Wafer No. 1

Before Transition

During Transition

After Transition

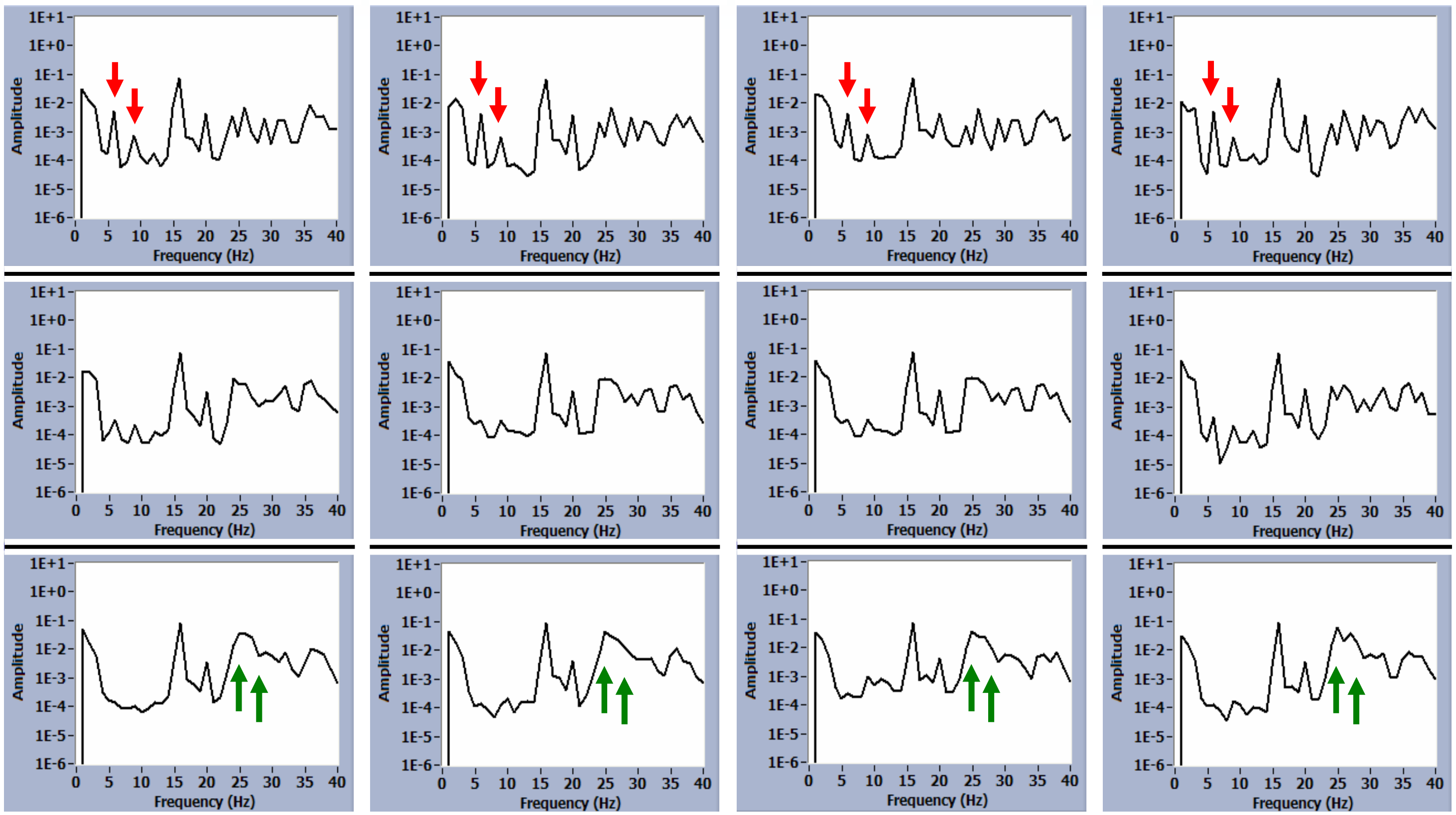


Spectral Analysis of Down Force for Wafer Nos. 2 – 5

Before Transition

During Transition

After Transition



Summary

- During blanket PETEOS CMP, larger cerium oxide particles induce higher COFs which also lead to higher RRs

- At higher RRs, correlation between theoretical wear and RR becomes non-linear. This is possibly due to a shift from mechanically-limited process (i.e. the model's assumption) to a chemically-limited process (due to nature of ceria particles)

- Transition to silicon nitride is also detected through:

  - Lower variance of shear force
  - Higher variance of down force
  - Higher COF

- Force spectral analysis shows unique spectral fingerprints capable of systematically distinguishing vibrational events before, during and after transition to Si_3N_4 during STI CMP